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OLD GLACIERS

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Pass of Llanberis.

J. C. Branner

THE

OLD GLACIERS

OF

SWITZERLAND AND NORTH WALES

BY

A. C. RAMSAY, F.R.S. & G.S.

LOCAL DIRECTOR OF THE GEOLOGICAL SURVEY OF GREAT BRITAIN, AND
PROFESSOR OF GEOLOGY IN THE GOVERNMENT SCHOOL OF MINES

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THE following pages originally appeared as one of the chapters in "Peaks, Passes, and Glaciers," by the members of the Alpine Club. This will account for the appearance of one or two brief passages not essential to the scientific bearing of the subject. In the form of a separate treatise it is hoped that it may prove useful, not only to the geologist specially interested in the study of British glacial phenomena, but also in some degree to the less scientific tourist who explores the mountains and valleys of North Wales.

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THE OLD GLACIERS

OF

SWITZERLAND AND NORTH WALES

INTRODUCTION.

EVER since the publication of De Saussure's great work on the Alps, the subject of glaciers has claimed a considerable and increasing share of the attention of scientific writers. The gathering of the snow in the higher mountain regions, its conversion into solid ice, the inner structure and movements of glaciers, their ancient extension and erosive action on their rocky beds, the origin of crevasses, moraines, and many other attendant phenomena, have all been the subjects of discussion; and in the writings of De Saussure, Charpentier, Agassiz, and James Forbes, the charms of style and

graphic illustration have invested these questions with an interest felt far beyond the circle of purely scientific readers. The subject has, however, many bearings besides those relating to existing glaciers, and in the following pages I propose chiefly to confine myself to that part of the history and antiquities of the glacier world the origin of which, though lost "in the far backward and abysm of time," yet, in a geological sense, so little preceded our own day, that the larger contours of hill and valley as they yet stand were already in existence, and probably all the forms of mollusca now living even then inhabited the northern seas.

It is now twenty years since Agassiz and Buckland announced that the valleys of the Highlands and of Wales had once been filled with glaciers. Few but geologists heard the announcement, and, with rare exceptions, those who cared at all about it, met the glacial theory of the Drift in general, and that of extinct glaciers in particular, with incredulity, and sometimes with derision. Rash writers still held that the far-borne boulder drift, so widely spread over the cold and temperate regions

of Europe and America, had been scattered abroad by mighty sea waves, set in motion by the sudden upheaval of hypothetical northern continents; and the polish and striation of the rocks in the mountain valleys, — the veritable signs of vanished glaciers,—were attributed by flippant writers and talkers to cart-wheels, hob-nailed boots, and the nether integuments of Welshmen sliding down the hills; as if the country had been inhabited by a monstrous race of primitive Celts — all clad in the famous armour of stone worn by Loupgarou and his giants, when they fought with the heroic Pantagruel—their sole occupation for illimitable ages having consisted in the performance of Titanic *glissades* upon the rocks. Now, however, the tide has changed, and for years the glacial theory (applied to a late Tertiary epoch in Britain and elsewhere) has not only steadily gained ground among geologists, but has even found its way into the writings of more popular authors. But ere the glacial theory could be applied to any part of our own country, it was necessary for competent observers to investigate the subject both of existing glaciers in

other regions, and of drift-ice in the northern and southern seas; and, accordingly, I have considered it needful for the thorough understanding of ancient British glaciers, that some of the phenomena now easily seen in Switzerland should in the first place be noticed. Agassiz, Forbes, Elie de Beaumont, Desor, and other authors have already described in detail the former great extension of Alpine glaciers, and I regret that I was not aware, till after four editions of this memoir had appeared in "Peaks, Passes, and Glaciers," that Mr. Charles Maclaren had already inferred the original overflow of the Aar glacier into the valley of Lungern, in his paper "On the Erratic Formation of the Bernese Alps," &c., 1852. All that I have written is, however, derived from personal observation, and in this respect, I believe, trustworthy; and some of the speculations are new. I now purpose to show, briefly, some of the relations of the extinct glaciers of Wales to those of Switzerland, and of both with the erratic Drift that often covers the lowlands.

PART I.

SWITZERLAND.

PART I.

SWITZERLAND.

EVERYONE familiar with the Alps is aware of fluctuations in the dimensions of their glaciers. It is recorded in the pages of Forbes, that since the year 1767 the glacier of La Brenva rose 300 feet above its present level and again declined, and the terminal moraines of the Rhone glacier, arranged concentrically one within another, bear witness to its recent gradual diminution. The great Gorner Glacier of Monte Rosa, also, is even now steadily advancing, and is said, within the memory of men not old, to have already swallowed up forty châlets and a considerable tract of meadow land.

But all such historical variations in the magnitude of glaciers are trifling compared with

their wonderful extension in pre-historic times. There is perhaps scarcely a valley in the High Alps in which the traveller, whose eye is educated in glacial phenomena, will not discern symptoms of the former presence of glaciers where none now exist; and in numerous instances, far from requiring to be searched for, these indications force themselves on the attention by signs as strong as if the glacier had disappeared but a short time before the growth of the living vegetation. So startling, indeed, are these revelations that for a time the observer scarcely dares to admit to himself the justness of his conclusions, when he finds in striations, moraines, *roches moutonnées*, and *blocs perchés*, unequivocal marks of the former extension of an existing glacier, more than a long day's march beyond its present termination; and further, that its actual surface of to-day is even 2000 feet and more beneath its ancient level. I know of no glacier to which similar remarks are not applicable, and to none more so than the familiar examples of the upper and lower glaciers of the Aar, which accordingly I select as examples.

The rounded forms of rocks and the striations on their surfaces produced by the flowing of glaciers over them, are familiar to all, through the writings of Agassiz and Forbes. The original asperities are by this process worn off, and, as is well known, the whole assumes a largely mammillated appearance; the surfaces being polished, grooved, and striated by the imprisoned stones and finer débris that lie between the solid weight of slowly progressing ice, and the rocky floor over which it passes. Let any one in going up the lower glacier of the Aar, attentively consider the mountains on either side, and he will observe the signs of glacial action somewhat above the present surface of the ice, as for instance, in the neighbourhood of the Pavilion of M. Dolfuss-Ausset on the left bank. Becoming accustomed to such indications, if he cast his eye further up the slopes, he will observe the same rounded and striated contours stretching up the mountains to a height of far more than a thousand feet, plainly marking both the breadth and height of the glacier at earlier periods of its history; while in the uppermost regions, the serrated and

weather-worn crags, that form the lips of the valley, now almost bare of snow, still define the upward limits, where the solid flowing ice in old times ceased to grind the rocks. It is certain that all glaciers must deepen their beds by erosion, and it may be, that when a glacier filled a valley to the bases of the serrated ridges, the thickness of the ice was not equal to its present mass, added to the superincumbent weight indicated by the signs mentioned above. There is, nevertheless, reason to believe that the glacier was once far thicker than at present: and this is further attested by numerous proofs of its original great longitudinal extension, the length of a glacier that originates in a large ice-field being, in a long valley of moderate inclination, generally more or less commensurate with its mass.

In 1852 I ascended the Ober Aar glacier with M. Daniel Dolfuss-Ausset. We left the Pavilion about two o'clock, and leisurely descended the lower glacier of the Aar. We then turned to the right, and, gradually ascending, skirted along the hills till we reached the neighbourhood of the upper glacier about half-past six.

It was a luxurious journey. M. Dolfuss-Ausset had four assistants with him, one of whom carried a couple of buffalo robes, the second a basket of provisions, and the third a small iron stove fitted with slips of firewood and a nest of iron pots. I had a guide from the Grimsel, since undergoing penal servitude for his share in burning the hotel a month or two later. We slept in a small stone hut, used for cattle, near the end of the glacier. A slab of stone at the door served for a table, and with the help of the stove, and the provisions carried by M. Dolfuss-Ausset's people, we made a comfortable supper, and lighting our pipes enjoyed a pleasant hour's chat over a glass of hot brandy and water before going to rest between the buffalo skins. Two things specially struck me. One of these was, that seen from this elevation, the planets seemed to *swim* in space. Another impressive circumstance was the utter stillness, when the night's frost (though in August) had arrested the smaller brooks.

At four next morning, M. Dolfuss-Ausset aroused us all with a blast on his horn. It was a clear frosty morning, and by and by it was

Viesch is 11,675 feet above the sea. The inclination is gentle, there being no difficult cliff like that which forms the chief impediment in crossing the Strahleck Pass. On either hand, craggy peaks of gneissic rocks rise boldly above the ice, forming the Ober-Aar-Horn and the Roth Horn, so steep, that in summer the snow only lies on them in patches. On the sides of the crevasses that are found almost up to the snowshed, it is easy to observe that *stratified* glacier ice has been formed, for never having been subject to any but a vertical pressure, the veined structure, now so well explained by Dr. Tyndall, is necessarily absent. But the forms of the adjoining peaks tell that the snow and ice lie thick, though of unknown depth; and were the covering removed, there is no reason to doubt that the rocky floor underneath would, at the snowshed, present striations sloping both down the valley of the Aar and in the opposite direction.

At the lower end of both the Aar glaciers, the terminal moraines are for the most part comparatively small, for in the greater part of these mounds as fast as matter is supplied, it is

attacked by the streams, that, flowing from the glaciers, speedily remove the smaller débris. Considering the great size of many of the blocks that lie on the surface of the ice, one is often surprised how comparatively rare is the occurrence of such masses on the terminal moraines; but this surprise ceases when we consider that in their slow downward progress, these blocks are constantly split at the joints and other crevices, and are thus gradually reduced by winter frosts, so that comparatively few reach the terminal moraine in their integrity. When they do get so far, they are then still subject to the same influence, till in time, many of them get so broken, that they also find their way to lower levels by the power of running water. In old glacier countries, where glaciers are now no more, the observer is often struck with the scarcity of moraines in positions where he might expect to find them; but his surprise ceases when he is aware of the facility with which the moraines of even large glaciers are often wasted as fast as they are formed; and if these existing glaciers disappeared, their moraines would in many cases soon be utterly obliterated.

Below the Lower glacier of the Aar, the stream winds through one of those gravelly flats, so frequent in old glacier valleys, and at its lower end, where this plain narrows towards the road that turns up to the Grimsel, a boss of granitic gneiss, well *moutonnée*, nearly bars the valley across which the path leads. It is partly covered by striations, well marked on the slope that looks up the valley, telling the observer, not only of the previous extension of the glacier thus far, but also that the ice which filled the plain pressed strongly on the higher side of the boss, and was forced upwards till it fairly slid over the rock, the lower part of the ice being quite unchecked by the opposing bar. I mention this especially, because similar phenomena were often pointed out by Buckland in describing the old glaciers of North Wales. On either hand, all the way from the glacier to this point, the mountain sides show the same mammillated contours that mark the rock above the ice, and a little farther down, the signs of glacial action become even unusually obtrusive. A large hill rises from the valley on the right, up which the road

winds to the Hospice of the Grimsel. On the left is the narrow gorge of the Aar, and on the other side of the hill, the sullen lake of the Grimsel half encircles it far above the level of the river. At its outflow the lake is partly dammed up by a little moraine-like débris; but it requires no soundings to tell that the rounded rocks close by, passing under the rubbish, form the chief retaining barrier of the water. On both banks, except when weathered, the rocks are ice-worn, and the lake is nearly looped into two by *roches moutonnées*, that project from either bank toward the centre, as in Llyn Idwal, Llyn Llydaw, and the lakes of Llanberis, if the last were undivided by the alluvial strip below Dolbadarn Tower. At its farther end a long, narrow, high, rounded barrier of solid rock (over which the glacier formerly poured) crosses the valley, damming up the lake in that direction; and here so great has been the pressure, that I found proof of the ice having been forced into a narrow transverse fissure, which it polished and striated quite out of the direction of its general flow. The lake lies in a complete rock-basin, similar

to some of the tarns of North Wales, and such as I only know in regions where glaciers once have been.

On the hill behind the Hospice, the glacial striations on the rocks following the sweep of the valley, gradually circle round to the further end of the lake, and it soon becomes apparent, that this hill itself is but a gigantic *roche moutonnée*, mammillated and striated all over, on which erratic blocks were left by the decrease of the glacier of the Aar, at a period later than that in which it rose so high, that it not only filled the hollow of the lake, and pressed upward over the ridgy barrier at its further end, but actually overflowed the entire hill.

If from its polished side you survey the opposite ridge of the Aar valley, the vast size of the old glacier becomes still more strongly impressed on the mind. A great wall of rock rises sharply above the river course, and on its side the striations which cover it have been deflected upwards at a low angle, the effect of the intense jamming to which the thick ice was subjected in its downward course, when obstructed by the great *roche moutonnée*, that

rises in the middle of the valley between the lake and the mountains on the opposite side of the Aar. Above this wall the mountain is still *moutonnée* almost to the summit, where at length the serrated highest peaks of the ridge rise sharply above the ice-worn surfaces.

The valley has been filled with ice almost to the very brim.

But the proofs of this fact are not yet exhausted.* In descending from the upper Aar glacier, I crossed that part of the Siedelhorn that overlooks the Grimsel, and then saw that the mountain was covered by similar indications of the former extension of glaciers; and, in 1858, in crossing the Grimsel Pass to the valley of the Rhone, I observed in the ascent, that the old striations *circle round* the sides of the amphitheatre of mountains that overlook the lake, indicating the grating of the glacier when the vast hollow was filled with ice. I then, led by old experience both in Switzerland and Wales, ventured to predict to my companion, Dr. Tyndall, that

* See Agassiz, *Études sur les Glaciers*, p. 253, Maclaren, &c.

when we reached the summit we should find the striations change their direction, and pass *across* the watershed. This proved to be the case, leading to a conclusion no less startling than sure, that the glacier here overflowed the ridge, and sent off a branch between the hills that bound the Todten-see in the direction of the valley of the Rhone, just as at the present day the great Aletsch glacier overflows its bank at the side valley of the Märjelen See, where an offshoot of ice, more than 100 feet thick, now terminates in the lake, but in olden times flowed far beyond to join the Viescher glacier on the east side of the Æggisch-horn. Similar signs are equally strong on the hills on the S.W. side of the Betten-Horn, where, after a solitary ramble on the lower part of the Aletsch glacier, I climbed the ridge, and observed that on the watershed the striations turn and run transverse to the direction of the Aletsch valley, crossing the hill towards the valley of the Rhone, thus indicating that the Aletsch glacier there also overflowed its channel, sending the surplus ice into the neighbouring valley.

I find my note-book well charged with des-

criptions of the ancient extension of the glacier between the Grimsel and Meyringen. Everywhere the signs are strikingly apparent, both below and far up on the mountain sides; but the details would scarcely add force to the foregoing observations; and to avoid repetition I omit all but one description. A little above Meyringen the Aar flows through a long, deep, and perfectly precipitous gorge, which the river has cut for itself in the limestone rock of the Kirchet. Looking down you see occasional potholes at various depths, formed by the gyration of stones, and marking different levels of the water during the excavation of the ravine. Above, on either side, the rock is all *moutonnée*, the striations running *westerly*, in the direction of the valley; and the surfaces are more or less strewn with moraine matter and huge erratic blocks of gneiss, syenitic-looking fragments, and other rocks that have travelled on the old glacier from the further recesses of the Oberland. Beyond the eastern entrance of the gorge, towards the opening of the Gadmen Thal, the mountains on either side of the Aar have been smoothed by ice

far above the level of the river; and angular and waterworn gravel, and syenitic blocks, lie on the eroded surfaces. A great alluvial plain, through which the river wanders, lies east of the Kirchet, and, but for this deep gorge cutting through the hill, the river would be dammed up, and the plain would form a long deep lake. In like manner, when the

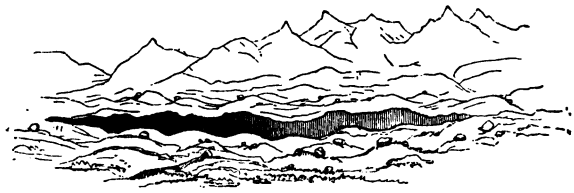

DIAGRAM OF ROCHES MOUTONNÉES BY THE GORGE OF THE AAR.

glacier overflowed the Kirchet, and formed the *roches moutonnées*, there must have been a long, broad, and deep lake of ice filling the valley of the plain to a height greater than the summit of the Kirchet, and pushing against and over that barrier of rock. As the glacier decreased, and no longer overflowed the rocks, it would for a time still abut

on the eastern side of the barrier. Finally, when it still further declined in size, the hollow of the plain (at present covered with alluvial débris) became filled with water, and formed a lake somewhat of the nature of the Märjelen See, but on a larger scale.*

GLACIER OF THE AAR FILLING THE HOLLOW BEYOND THE KIRCHET.

Thus it would remain till the running water by degrees cut a channel through the Kirchet, as deep as the bottom of the lake, then partly filled with mud and other ice-drifted deposits. I was long much puzzled by the stratified and *drift-like* appearance of some of the débris (including boulders) on the lower sides of the hills that bound the plain, till it occurred to me that the

* The former existence of a lake here has been inferred by previous writers.

conditions mentioned above explain this circumstance; for, just as the bergs that break from the Aletsch glacier scatter blocks and smaller gravel amid the sand that sinks in the Märjelen See, forming boulder strata there *, so in the case of the old lake above the Kirchet, when the Aar glacier en-

THE PLAIN ABOVE THE KIRCHET AS A LAKE, WITH ICEBERGS.

tered it, icebergs laden with moraine matter floated in the water, and discharged their freights wherever they chanced to roll over or to melt.

It would be easy to show proofs of the greater extension of this glacier below Meyringen, where there still remain ample signs of glacial action.†

* The Märjelen See is drained every eight or ten years, by the temporary opening of a sub-glacial passage through the Aletsch glacier. Its bottom is partly strewn with boulders mixed with finer material drifted by small icebergs.

† See Maclaren.

Its mass was then swelled by other tributary streams of ice, one of which flowed down the Gadmen Thal; and I am inclined to suspect it might be shown, that at one time the glacier was so large, that on the Meyringen side of the watershed of the Pass of the Brunig, it ran into the tributary valley that leads to the Pass, and even overflowed its summit and descended to the Lungern lake and beyond the Sarnen-see. For, between that lake and the watershed, there are many scattered blocks of gneiss, which, if maps may be trusted, must have passed down the Aar valley to find their way across the Pass, seeing that there are no direct channels leading up to the gneissic mountains on the south, through which glaciers might have conducted these metamorphic blocks into the Jurassic and cretaceous valley of Lungern, where the rocks are comparatively unaltered. The only possible route, indeed, seems to have been the circuitous one by the Aar valley and so over the Pass of the Brunig.

Such are a few of the more striking phenomena connected with the glacial history of

the valley of the Aar, and similar observations might be extended to that of the Rhone and to many other Alpine valleys. The largest of existing glaciers is but of pigmy size when compared with its predecessors. But great as they were, they had their traceable limits, even if, like Arctic glaciers, they held on till they reached the sea. It has been ably argued by Playfair, Venetz, Charpentier, and Forbes, that on the north, when no sea was present, this limit was the range of the Jura; or, in other words, that the ice overspread the vast expanse of undulating ground that lies between the Oberland and the Jura, against which the glaciers were arrested in their course, and there deposited as moraine, about 500 feet above the existing Lake of Neufchatel, those celebrated blocks of which the Pierre à Bot is the most conspicuous. The blocks of Monthey also, opposite Bex in the valley of the Rhone, are supposed to have had a like origin.

I think (with diffidence) that there are grounds why this mode of accounting for the position of these blocks both on the Jura and

above Monthey should not be received*, chiefly for this reason, that, if it be true, the country between the Jura and the Oberland ought to show numerous traces of moraine matter, arranged somewhat in the ordinary manner in which it now occurs, in connection with existing or ancient glaciers, but on a grander scale. But the loose detrital matter that in a great measure covers the country, though of the same general material, is very different in its arrangement from that of moraine débris. Wherever I have seen it, it may be described as resembling in all its essential characters the marine boulder-beds of other glacial Drifts, as these strata occur in Europe and in North America; and it is perfectly comparable to some of the boulder-drifts of Britain, which were accumulated when the glaciers of the Highlands and of Wales descended to the sea.

Between Schaffhausen, Zurich, Zug, and Lucerne, the country is more or less strewn with gravel derived from the waste of the Alps.

* Unless it may be argued that they were carried to the Jura by glaciers of older date than the Newer Pliocene Drift, and afterwards associated with later gravel.

This gravel is distinctly *stratified*, (being sometimes interbedded with sand and clay,) and consists chiefly of water-worn stones, mixed with angular and subangular fragments and blocks of all sizes up to several yards in diameter. Many of the stones and blocks are striated or scratched in a manner similar to those found in glacier moraines, and equally resembling those found in the stratified gravels and boulder clays of the northern plains of Germany, North America, the lowlands of Scotland, the Midland Counties, and North and South Wales. On the road between Horgen on the Lake of Zurich, and Zug, boulders and stratified gravel are common, and on the Zug side of the watershed, great mounds of drift are of frequent occurrence; not arranged symmetrically like moraines, but rather resembling the rough hummocks of irregularly stratified glacial rubbish in the valley of the Dee, in Aberdeenshire; and also many mounds in the lowlands of Scotland, the forms of some of which have perhaps been modified by atmospheric agencies acting on the Drift that originally covered the country.

On the north bank also of the Lake of Geneva, far above the lake, in the railway-cuttings and elsewhere, the superficial detritus has even a more typically drift-like character, being composed of well stratified gravel, sand, and clay, charged with boulders of gneiss, granitic rocks, limestone, &c. This gravel is mostly composed of water-worn fragments, the boulders being both rounded and angular, and some of them showing scratches and striations like those produced by the action of ice. The railway station at Geneva, stands above clay well charged with glacial boulders.

East of the Lake of Geneva, on the hills that bound the valley of the Rhone, opposite Bex, lie the celebrated blocks of Monthey, so well described by Professor Forbes, who considers them to have been deposited from the surface of a great glacier that once filled the valley. A mountain torrent passes close to Monthey on the south, and in a deep natural cutting, forming the bank of the stream by a mill, the superficial stony detritus is rudely stratified, just like many an ordinary section in British Drift. It is full of large boulders of

gneiss, granite, sandstone, &c., and from the quantity of fragments of limestone it contains, the gravel is partly consolidated, through the agency of infiltrated carbonated water carrying away and re-depositing calcareous matter among the fragments. Between this point and the blocks of Monthey small boulders are of frequent occurrence. The larger ones lie on both sides of the torrent, at greater elevations than the section by the mill, while those of greatest size are scattered chiefly among the vineyards and beautiful groves that lie above the town, near the winding road that ascends the mountain. I wandered among them half a summer's day, pleased and amazed by their beauty and great size, and the evidence of power conveyed to the mind while reflecting on the agency that bore these ponderous masses so far from the parent rocks, and left them perched on this hill, from 500 to 600 feet above the Rhone. All those of largest size that I saw are of granite, and the most massive of all, lying in a vineyard, I measured. It is twenty-two paces in length, and nearly equally broad and high, and probably contains between 17,000 and 18,000 tons of

rock. On its flat summit there is a good-sized summer-house, with a small garden containing cherry trees, reached by a flight of steps. Others of smaller dimensions are formed of gneiss, and some of sandstone. They are now being ruthlessly quarried for building stone, for a bridge across the Rhone; but so profusely are they scattered all along the hill, that it will take no ordinary amount of blasting sensibly to diminish their number.

Several fresh cuttings had been made close to the road; and where the blocks do not rest directly on the shale that forms the hill, *they lie on and in* a sandy gravel roughly stratified, the material of which consists of fragments of granite, gneiss, limestone, and sandstone, generally well water-worn, a large proportion of the pebbles being quite rounded by abrasion like pebbles on the shore. This débris is not comparable in angularity or arrangement to any moraine I ever chanced to see; and in the water-worn surfaces of the pebbles, it rather resembles the rounded chalk flints in many gravels; being in truth less angular than much of the Drift of the Midland Counties, Anglesey,

or of some of the Caernarvonshire beds with marine shells. Like these, too, it bore to my eye the signs of aqueous deposition; and the occurrence of great blocks both *on and in* these gravels I cannot but connect with the circumstance that similar drift-like strata encircle the Lake of Geneva, rising high above its level. From thence these strata range across the lowlands of Switzerland at the base of the Jura, towards Zurich and Schaffhausen, covering the hills hundreds of feet above the level of the lakes of Zurich and Zug, each of which lies more than 100 feet above the Lake of Geneva.

If this view of the subject be correct, it follows that during part of the period when the North of Europe was submerged to receive the marine Drift, Switzerland also lay beneath the sea, *at least* 2000 feet beneath its present level, that being about the height of the blocks of Monthey above the sea.* Connecting this

* In Wales and Scotland the drift rises considerably higher. Since the first edition of this memoir was published, Mr. Darwin has called my attention to the circumstance that Agassiz observed that the erratic boulders on the Jura lie *on and in* stratified sands and gravels, and yet he explains all the phenomena by *glacier* action alone. Mr. Darwin

drift with the original extension of the Swiss Glaciers, it seems probable that many of the greater glaciers found their way down to the level of the sea—as they do now in the north of Norway and in Greenland — from which icebergs breaking off floated moraine matter into the Alpine fiords, and outwards across the submerged territories that lay between the Bernese Oberland and the Jura; and thus it happened that on the flanks of the latter mountains and above Monthey, the stranded bergs deposited their freights, sometimes including those gigantic blocks that now astonish the traveller. This also accounts for the scattering of numerous boulders all over the intermediate country, and for the mingling of these with stratified and water-worn detritus, the far transported material

himself, speculating on the data of Agassiz, states what I conceive to be the true theory, viz. that the country was partially submerged, and icebergs derived from Alpine glaciers floated the blocks to the Jura. (*Narrative of the Voyages of the Adventure and Beagle*, 1839. Addenda, vol. iii. p. 615.)

Mr. Daniel Sharpe asserted that the Swiss mountains show traces of marine erosion at different levels. (*Journ. of the Geolog. Soc.* 1856, p. 102.)

See also Murchison, *Proceedings of Geolog. Soc.* 1849, vol. vi. p. 65.

of which must often have been rounded by the breakers on the shores, and scattered by floating coast-ice, like the mixed deposits so frequent in the British Drift.

When this view is taken of the old glacial phenomena in Switzerland, it is remarkable how closely it accords with what has been observed respecting the ancient glacial history of North Wales, and the Drift which, surrounding that country, penetrates many of the valleys, and rises far up the mountain sides. This can be better studied as a whole in Caernarvonshire, than in any other part of Wales, and I shall therefore describe Snowdon and the neighbouring mountains as a type.

PART II.

THE OLD GLACIERS OF NORTH WALES.

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THE OLD GLACIERS OF NORTH WALES.*

BETWEEN the Snowdon range and the Menai Straits, the country descends to the sea in a series of undulations, in great part covered by Drift, through which weatherworn bosses of rock protrude, often with rounded outlines, the smoothness of which has been much destroyed by exposure to the weather.

* The striation of the rocks, and most of the moraines mentioned in the following pages, are marked on the map. A few passages near the close of this memoir are extracted from other papers written by myself for the Journal of the Geological Society, the Edinburgh Philosophical Journal, and the Catalogue of rock specimens in the Museum of Practical Geology.

Passing from Caernarvon towards Llanberis, when we reach the marshes near Cwm-y-glo *, the Drift disappears from the valley, the rocks stand out more boldly, and by and by, on both shores of Llyn Padarn†, the experienced eye has no difficulty in distinguishing clear signs of glacial action; for the rocks, where unweathered, are round and mammillated, and their smoothed surfaces are sometimes grooved, the striations running north-west in the direction of the valley and of the length of the lake. Many beautiful instances of this occur by the sides of Llyn Padarn, and one obvious example may be seen in a little rounded islet, near the lower end of the lake, close by the railway. With a little search, numerous like examples are found on the rocky slopes many hundreds of feet above the level of the lake, and on these all the striæ run north-westerly. On the map I have traced

* The Valley of Coal, or, more probably, of Light. Lying in the Lower Silurian rocks, this valley has nothing to do with the Coal-measures of the geologist; though I once found certain ignorant miners sinking for coal in the black Silurian slaty shales of the district.

† *Padarn*, a Welsh saint; Padarn's Lake.

them in forty-six places, over a space nearly two miles in breadth, between the northern slope of Bryn-mawr * and Clegyr †, the lake lying between. Here and there, on the side of Clegyr next the lake, little patches of moraine matter lie amid the rocks, while beyond its north-eastern slope, there is a broad expanse of Drift stretching towards Nant Francon.

The same is the case by the sides of Llyn Peris, both low and high;—as, on the unbroken surfaces of rock amid the great slate quarries below Elidyr-fach; on the opposite slopes of Cwm Ael-hir ‡; and far above to the very summits of Pen Carreg-y-frân § and Derlwyn ‖;—where indeed, the striations fairly cross the watershed, and strike nearly westward, in a manner comparable to the change of direction of the groovings on the summit of the ridge below the Bettenhorn, that divides the valley of the great Aletsch glacier from that of the Rhone. Blocks of felspathic porphyry, that have travelled from the higher parts of Snowdon, lie

* Big Hill. † Craggy Rocks. ‡ Eye-brow Valley.
§ Crow-rock Hill. ‖ Oak-copse.

scattered about; and on the very summit of the ridge near Derlwyn, one stands perched on the crags, in a manner at once suggesting that it was left by the ice where it now stands.

BLOC PERCHÉ NEAR DERLWYN, PASS OF LLANBERIS.

A beautiful glaciated surface of hard Cambrian grit may be seen by the bend of the road, near the Copper-mine, above Llyn Peris *, close to the small octagonal building marked "office" on the Ordnance map, where the striations running down the valley are as fresh as if the ice had but lately disappeared. Other rounded faces slip into the lake; others form mounds of rock above the road; and finally, often decayed, they pass far up among the Cambrian grits, to the very summit of Pen Carreg-y-frân. On the opposite slopes, at the mouth of Cwm

* *Peris*, a Welsh saint.

Roche Moutonnee with Blocs Perchés, Pass of Llanberis.

Dudodyn, the rounded forms are also apparent, but the finer glacial markings have often disappeared from the softer surfaces of the slate.

Up the Pass, every step beyond Llyn Peris, the signs of a vanished glacier become more and more apparent. Erratic boulders mingled with smaller moraine matter, lie on the roadside and up among the rocks, easily distinguished by the experienced observer from more modern blocks and talus that lie below the weathered cliffs. On both sides of the valley, the rocks, strewn with blocks, frequently present the well-known *moutonnée* form, more or less perfect; and this is especially plain towards the turnpike gate, and near Pont-y-gromlech *, where bosses of felspathic porphyry rise like little hills in the middle of the valley, something like miniatures of that behind the Grimsel. Though their sides have been scarred by the winters' frosts, their summits, roughened by the weather, still retain the largely mammillated form impressed on them of old by the grinding ice; and while the

* Cromlech Bridge.

tourist, who sees something in scenery beyond mere external form, is often puzzled to account for the numerous blocks, that, perched on precarious points, seem as if they ought to have taken a final bound into the lower valley, the well-pleased eye of the geologist versed in ice, at once detects that they were let gently down where they lie by the melting of the diminishing glacier.

Further up the valley, behind Blaen-y-nant *, a brook descends from the hollow of Cwm-glas.† A little way up its banks a good-sized moraine, afterwards to be more particularly noticed, has been cut through by the stream, and bends up both its banks. Above this, going up the Pass, the ground on the right is all covered with moraine débris, and nearly opposite the great fallen blocks of stone, miscalled a Cromlech, a huge mound worthy the name of a hill rises in the valley between the road and the upper side of the entrance to Cwm-glas. So large are some of the angular blocks with which it is studded, that for some time I was doubtful if the hill did

* "The Mouth of the Valley," where the house stands.
† The Grey Valley.

not chiefly consist of a solid mass of felspathic porphyry, but the mixed nature of its fragments, its form, and position, after many a visit, forced me to the conclusion that it is the relics of a large moraine, shed from the *upper* side of a glacier that once descended from Cwm-glas, and abutted on the opposite side of the Pass.

Below Pont-y-gromlech, there are other traces of moraines, and several erratic blocks—one of them of greenstone—lie perched on a large rounded boss of felspar porphyry. The ice-furrows on its surface are almost all weathered away, but such as are traceable trend towards Llyn Peris, and, as is frequently the case, the more broken side of the *roche moutonnée* faces down the valley. Opposite, above the bridge, on the Snowdon side of the valley, a great dark wall of rock rises abruptly from the broken lower slopes, about a quarter of a mile from the road. From the bottom of the Pass it looks almost inaccessible, but half way up there is a rough terrace, at the foot of a greenstone dyke that forms in part the face of the cliff. The slope of the precipice is about 68° towards the Pass, and in one place especially, the wall of

rock is polished, and striated in at least six principal grooves, which slope down the valley (not down the hill) at an angle of 12°. Some of them are deeply graven, from two to two and a half feet wide, and twelve or eighteen inches deep, and they run so evenly along an almost vertical wall of rock, that the idea is at once suggested, that they were formed by the long-continued pressure of a glacier so large, that it filled the valley to a far greater elevation than the grooves, and by reason of the huge overlying mass of ice, a middle stratum, as it were, of the glacier was jammed against its bounding walls so powerfully, that by help of the grinding of imprisoned stones, in time, it graved the strong furrows still so perfect.

To the very top of the Pass the same kind of evidence, both of moraine débris and striation, continue unabated, especially on the *higher* slopes on the north-eastern side of the valley, where, above the modern shingle and broken cliffs that overlook the brook, numerous *roches moutonnées* remain, still partly unweathered, and here and there dotted with *blocs perchés*. By

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Roche Moutonnée and Bloc Perche near the top of the Pass of Llanberis.

the road at the twelfth milestone a good instance occurs of a *roche moutonnée*, easily seen by those who are satisfied with roadside geology. Its curving outlines are perfect on the top, but at the sides it has been shattered by the weather.

Close by the watershed at Gorphwysfa *, the striæ on the rocks still run north-westerly in the direction of the Pass, like those that must now be forming at the snowshed of the Upper Aar and other glaciers. Once fairly across the watershed, where the valley widens, they rapidly curve round with the average slope of the ground, some passing in the direction of Nant-y-gwryd †, towards Capel Curig ‡, and others down Nant Gwynant.§

Thus far some of the more obvious glacial phenomena in the Pass of Llanberis can scarcely fail to strike the most hasty observer, and if we ascend some of the tributary valleys that run

* The "Resting-place," after the long ascent from Llanberis, Beddgelert, or Capel Curig.

† "Fathom Valley," or of the length of a man. The meaning is obscure.

‡ *Curig*, a man's name. Curig's Chapel.

§ White Valley; or literally, Whitevale Valley.

upwards into the heart of Snowdon, they become still more impressive.

This mountain, the highest and noblest in the district, is bounded on three sides by valleys, which in all respects are unsurpassed in geological interest and wild beauty, by any in North Wales. On the north-east lie the bare crags of the narrow Pass of Llanberis, on the east the softer beauties of Nant Gwynant, and on the west the long drift-covered slopes of the broad depression that runs from Llyn Cwellyn * to Beddgelert. In the midst of these, the mountain rises in a tall peak 3571 feet above the sea, its base being formed mostly of old lava beds of felspathic porphyry, and the topmost thousand feet chiefly of stratified felspathic tuffs and ashes. In these rocks six vast hollows have been scooped by time, forming the wild upland valleys of Cwm-glas-bach †, Cwm-glas, Llyn Llydaw ‡,

* *Cwellyn*, properly *Cawellyn*, a basket, hamper, or creel. So called from the fishing-creels once used in the lake.

† Little Grey Valley.

‡ *Llydaw* is the Welsh name of Armorica, but there seems to be no sense in this interpretation. *Lludw* means *ashes* or *cinders*, and it is remarkable that on parts of the slopes round the lake, there are consolidated Lower Silurian volcanic ashes, still so scoriaceous-looking, that even a person who is no geologist might readily recognise them as volcanic.

Cwm-y-llan *, Cwm-y-clogwyn †, and Llyn du'r Arddu ‡, in some of which the signs of glacier ice are even more striking than in the Pass of Llanberis itself.

Just above the turnpike-gate in the Pass, Cwm-glas-bach strikes up towards the top of Snowdon. The cliffs of Llechog §, formed of felspathic porphyry, bound it on the west. A lower ridge separates it from Cwm-glas on the east, and its upper end is formed of a rough semicircular sweep of beds of consolidated felspathic tuffas. The rocks at the upper end of the valley, often bare of vegetation, were partly smoothed by a glacier that descended from the

* The Enclosed Valley.

† The Craggy Valley.

‡ *Gardd*, or *Ardd* when preceded by the article *yr* (the), means a garden, and this name has often been translated the "lake of the black garden." Such a name, however, seems to have no sense when taken in connection with the locality. *Arddu* also means "the extreme of blackness," and lying, as the pool does, in a deep hollow at the base of a tall black cliff, the name literally signifies "the blackest black lake," or, as it might be freely translated into Scotch, "Pit-mirk Loch."

§ The laminated or "flaggy cliff," or precipice. The great beds of felspathic porphyry interbedded with slaty bands stand on end, and from below have a largely laminated aspect.

snows of Crib-y-ddysgyl *, and further down the felspathic porphyry soon begins to show strong signs of glacial abrasion, which continue all the way down to the Pass. These surfaces, though decayed and roughened by age, weathering and splitting at the joints, are still often wonderfully perfect in form. Distinct striations are, however, rare, but when they do occur, they run north and north-north-east, that being the direction necessarily given to them by a tributary glacier, that during the glacial period descended the valley to swell the main mass of ice in the Pass.

But it is in the adjoining valley of Cwm-glas that some of the most perfect remains of glacier action are to be found. First there is the immense moraine heap, lying between the precipice south of the road and Pont-y-Gromlech. As already stated, I believe it to have been formed by a glacier that descended north-

* "The Toothed Dish." The upland valley bounded by this hill is one of those cauldron-shaped hollows that in Scotland would be called a "Corry," and the serrated edges of its cliffs may well be likened to teeth. "*Crib-y-ddysgyl*," "Teeth of the Dish."

ward from the high recesses of Cwm-glas, and which fairly crossed the Pass, till its lower end abutted on the south side of Y Glyder-fawr * below Esgair-felen.† On the side of this glacier that faced up the Pass, there being no running water to bear away the débris, moraine matter might well be shed and accumulate to a vast amount, in the manner that took place, on a larger scale, from the upper side of the Glacier des Bois when it formerly crossed the valley of Chamouni; while from the side of the glacier that faced down the valley, the chief part of the moraine would naturally be destroyed almost as fast as formed, by the streams that flowed from beneath the ice; just as at present in Switzerland the terminal moraines of the Rhone glacier and of the lower glacier of the Aar never gather to an amount at all commensurate to the quantity of débris that is constantly floated down to them on the ice. Since the disappearance of the glacier of Cwm-glas, the stream that drains the Pass of

* The *Great Glyder*. I cannot get at the meaning of *Glyder*, and shall be glad of a rational explanation.

† The Yellow Shin or Ridge.

Llanberis has cut away the chief part of the huge upper moraine, but a large section of the rubbish still remains to attest its former size. Afterwards, when the glacier decreased, and retired behind the spot where the house of Blaen-y-nant now stands, an ordinary terminal moraine was shed from its end, and clear traces of the débris still run in a long broad north-western line that crosses both the brooks on either side of the house. Not far behind the house there is a large moraine lying on the slope of the hill on both banks of the western brook. It consists of heaps of boulders, clay, and angular gravel and blocks, identical in composition and in general aspect with many Swiss moraines. Some of the stones are scratched, the lines crossing each other confusedly; and the great mass of the moraine is formed of three or even four concentric elliptical mounds, which merge together at their bases, and mark on a small scale the gradual decrease of the Cwm-glas glacier. These circle round the north side of a *roche moutonnée* that, in the middle distance of the drawing, rises like a little hill.

Moraines and Roche Moutonnée at the Mouth of Cwm-glas.

A little behind the hill, about half a mile south of Blaen-y-nant, a beautiful and most perfect terminal moraine,—grass-grown, but still strewn with travelled blocks,—ranges across the valley between the brooks, almost as regular in form as many an artificial earthwork. It is between 1200 and 1300 ft. above the sea. Higher up on the west side of the valley, the striæ on the rocks run N.N.E. below the space where the glacier in a cataract of ice once rolled over the cliffs that now appear so grim. Three white threads of water glance on its black sides, the sole representatives, in another form, of the jagged ice-fall, that, on a smaller scale, must have resembled the great ice-cataract of the glacier of the Rhone. The slope, though a little toilsome, is easy of ascent, and beyond the rocks, there lies, in the innermost recess of the mountain, an upland valley, unmatched in Wales for wildness, and in which I never met a human being, though I have been in it more times than I can tell. On three sides it is bounded by tall cliffs and mountain peaks, in the midst of which lie two little deep clear tarns, about 2200 feet above the sea, each in a

perfect basin of rock, in this, on a small scale, resembling the Todten-see, and the lake behind the Hotel of the Grimsel. Between these pools and the cliff below, an immense quantity of moraine débris, derived from Crib-goch *, cumbers the ground. The rocks on which it lies are often perfectly smoothed, rounded, and deeply grooved; and the striæ that lower down the valley strike straight towards the Pass, here branch to the south-west and south-east, following the courses of two minor valleys, that branch at the south end of this recess, on either side of a peaked ridge that descends from Crib-goch to the ground between the pools. Tiny moraine mounds scattered about, tell of the last remnants of enduring ice, ere the shrunken glaciers finally melted away in the uppermost recesses of the mountain.

Having reached the upper end of Cwm-glas, if the explorer be indifferent to the hackneyed route of the posting tourist, he cannot do better than climb the ridge of Crib-goch, and walk

* "The Red Teeth," a name perfectly applicable to the serrated edge of this ridge, that, in the glacier days of Wales, rose, scarred by the weather, above the ice.

along its edge towards the summit of Snowdon. There, if the weather be clear, he may see below him three of the glacier valleys that radiate from the summit of the mountain. The rocky amphitheatre of Glaslyn and Llyn Llydaw lies on the east, the deep glen of Cwm-y-Llan* on the south, and on the west the broad, precipitous, circular hollow of Cwm-y-clogwyn, in which, with a favourable light, he may see faintly the terminal moraine of an old minor glacier, circling the west side of the central pool of Llyn-goch. The last is best seen from the sharp ridge that leads to Beddgelert.

Near the route back to Llanberis, a great moraine lies on the north and west of Llyn du 'r Arddu. This deep-set little tarn (that often rests unstirred even when a gale is blowing) lies at the base of a high cliff of felspathic porphyry and greenstone, mostly inaccessible except at its eastern end. Once with a companion I climbed it in a frosty December morning, after a slight fall of snow. It took an hour or more, for we were obliged to help each

* The term "*Llan*" is now commonly applied to a parish church. It literally means an "enclosure."

other with our hammer-belts, and occasionally to cut steps with hammers in the ice and crumbling rocks. By the outlet of the lake the grooves on the rock run north-westerly, and a large *roche moutonnée* lies a little nearer the cliff, sprinkled with *blocs perchés*. A great stony moraine-mound, covered with angular blocks from the neighbouring heights, circles round the lake, and rising high above it on the north, in a long steep slope falls more than half a mile down Cwm Brwynog.* From the old mine-shed by the road, successive concentric heaps of moraine rubbish are distinctly traceable, the highest of all being about 2250 feet above the sea. Huge blocks lie scattered on the surface, one of which, half way down the slope, measures about 18 yards by 14 by 10, and probably weighs nearly 5000 tons. A loose stone, several yards square,—not a severed part,—lies on its summit, perhaps in the very position it occupied when both were left by the ice.

At first it is difficult to understand how a moraine so large could have been deposited by so small a glacier, for the upper side of the

* Rushy Valley.

moraine lies little more than a mile from the peak of Snowdon, and less than a mile from the slope of Crib-y-ddysgyl, from the snow-drainage of which the glacier was formed that flowed over the eastern end of the cliffy ground, and passed down the hollow of Llyn du 'r Arddu. But the difficulty is lessened to those who have seen the prodigious amount of débris that often fringes the sides and ends of some of the small glaciers that lie on the higher slopes of the Alps. These, once united to the great glaciers that fill the valleys below, are now, shrunk in size, no longer strong enough to join them, but melt and deposit great heaps of rubbish on the adjacent slopes.

Beyond this moraine, with sufficient search, many ice-rounded surfaces of rock may be seen in Cwm Brwynog, their original striations being often decayed, but when visible they run north-west and north in the direction of the slope of the valley.*

* I have, however, often thought that the lower part of this valley is covered by Drift, and that if a tributary glacier from it ever *joined* the main one in the Pass, it must, of course, have done so before the deposition of this drifted material.

On the west, close below the peak of Snowdon, lies Cwm-y-clogwyn*, enclosing three little lakes. It is easily reached in less than two hours from Llanberis, either by the route of Bwlch-y-Maescwm†, or by Bwlch-y-Cwm-brwynog‡, at the west end of the precipice of Clogwyn du 'r Arddu. Immediately below this watershed, on the south, the lake called Llyn Ffynnon-y-gwas§ is possibly dammed up by moraine matter, merging into the long slope of drift that runs down to Llyn Cwellyn.‖ A cliffy escarpment, over which the brooks leap, crosses the entrance to Cwm-y-clogwyn, but it is easily accessible, and on the summit of a kind of enclosed tableland lie three tarns; circled by crags, the loftiest of which,—Pen-Wyddfa¶,—or the peak

* Precipice Valley.

† Literally, "The Gap of the Plain of the Valley," or "Valley-plain-gap." This *Bwlch*, or gap, in the mountains opens on a broad inclined plain or slope of Drift that descends towards Llyn Cwellyn and the road to Beddgelert.

‡ Rush-valley-gap.

§ "*Gwas*" means a "man-servant," and "*Ffynnon-y-gwas*" the "spring" or "well of the man-servant."

‖ See p. 95.

¶ The meaning of "*Wyddfa*" seems to be quite uncertain. It is said to mean "wild, untilled land," and also "the place of presence" (?), or "the eminence" pre-eminently.

of Snowdon, shoots high into the air, more than 1500 feet above the lakes. The whole valley is what in the Highlands of Scotland would be called a Corrie (or cauldron), a Celtic name that still lingers in Wales on the north face of Cader Idris, though its meaning is now lost to the Welshman.

On the ice-worn surfaces of greenstone and felspathic porphyry, which form the bottom of the valley, striæ are easily found, running north-westerly towards its mouth. It is difficult to unravel all the minuter details of the glaciation of a valley from which enduring ice has so long vanished; but after many a visit, I came to the doubtful inference, that a glacier probably at one time covered the whole bottom of the Cwm, which is still more or less covered with true moraine matter. This is not the less probable by the circumstance that due west of Llyn-y-nadroedd* the rocks are polished and grooved to the top of a low part of the bounding ridge, as if the glacier had once filled the valley up to this point and overflowed towards

* Snake's Pool.

Llyn Cwellyn.* Afterwards, as the supply of snow decreased, or the climate ameliorated, the glacier seems to have much diminished and split into three, for a minor moraine encircles Llyn-y-nadroedd on the north and east, and another beautiful small one made of angular blocks and stones, now covered with vegetation, bounds Llyn-goch† on the west and south-west, while a third dams up Llyn-glas. A long broad heap of débris runs in the direction of the length of the valley between Llyn-y-nadroedd and Llyn-goch, perhaps shed from the adjoining sides of two minor glaciers passing down to the lakes. If this be true, the débris toppled over from the sides of the glaciers, and formed a mound between them, on which three enormous blocks of porphyry still lie.

Of all the valleys that lie in the heart of Snowdon, the largest and most magnificent is that of Llyn Llydaw. It is easily reached from Llanberis over the summit of Snowdon, or by Cwm-glas over the ridge of Crib-goch; but

* Unless these striations were formed by drift ice. See pp. 19, 20, 39 and 89.

† Properly "*Llyn-côch*," or Red Lake.

both for the lovers of scenery and for those who specially care to observe its glacial phenomena, it is better to go up the Pass of Llanberis to Gorphwysfa, and so strike into the valley; or, if there be time, to cross the broken ground to the right of Nant Gywnant, and from thence ascend Cwm Dyli* by the cataract to Llyn Llydaw. This route is most instructive, especially if the sides of the Pass have been explored before; for then, up to the watershed of Gorphwysfa, the eye readily comprehends all the combined signs of an old glacier of the largest size in Wales, especially when habit has accustomed the explorer to detect in every stage of decay the signs left by the glacier. As already mentioned, for hundreds of feet up the sides of the valley, all the striations run north-westerly *along* the hills; except in tributary valleys, or occasionally at great heights, where they sometimes converge a little towards the Pass, as in the higher part of the hollow above Pont-y-gromlech, that leads up to Y Glyder-fawr; or on the hillside about half a mile due

* Correctly, *Dylif*, meaning "the rush of waters." It may be translated "Cataract Valley."

west of Gorphwysfa; and again on the water-shed directly west of Llyn-Cwm-ffynnon, where they run both towards the Pass and Nant-y-gwryd.

Close by Gorphwysfa the striæ run across the water-shed, as if at its culminating point the piled-up snow and ice had flowed in two directions, on one side down the Pass, and on the other towards Nant Gwynant, just as it now does at the snowshed of the upper glacier of the Aar. At the corner of the road at Bwlch-y-gwyddel* some of the striations run east and west, as if part of the radiating mass turned down Nant-y-gwryd, where the grooves run about E.N.E. towards Capel Curig. On the Snowdon side of the brook that runs from Gorphwysfa to Nant Gwynant, they strike E. and S.E. with the run of that branch valley; but on a lower level, at the mouth of Cwm-dyli on both sides of the waterfall, they run nearly due east over the top of the cliffy ground, showing that a glacier once passed through this opening into Nant Gwynant. Further south, opposite

* Irishman's Gap.

Gwastad Agnes*, and on the northern part of the ridge of Gallt-y-wenallt†, the grooves on the rounded rocks strike S.E. and S.S.E., and finally curving round to the S. and S.W. they strike fairly down the valley on the western side of Llyn Gwynant, and right across the mouth of Cwm-y-Llan.

The meaning of the direction of the striæ at the mouth of the Cwm-dyli is this:—A glacier, about three miles in length, flowed eastward, from below the peak of Snowdon, through the valley of Llyn Llydaw and Cwm-dyli, and united with a stream of ice, that, when the glaciers of Wales were at their largest, descended from the direction of the top of the Pass of Llanberis and Pen-y-gwryd, where the ice was then of very great thickness, representing the accumulated snow-drainage of a large part of the broad mountain slopes that lie between the eastern peak of Crib-goch and the southern side of Y Glyder-fawr. I consider that the result of this was to produce a mass of ice not less than 500 feet thick, just

* Agnes' Plain or Flat.

† White-hill; literally, "White Hill-hill."

above the present watershed at Gorphwysfa, for, without this, I cannot account for the longitudinal glacier striations running *along* the sides of the Pass of Llanberis 1300 feet above its bottom.* If this hypothesis be correct, then it follows that in the opposite direction the mass flowed down towards Nant Gwynant, being so thick at Gorphwysfa, that its surface was higher than the broken ground between Llyn Teyrn† and the upper part of Llyn Gwynant. On this ridge, overlooking the bottom of Cwm-dyli by the waterfall, the striations strike south-easterly, as if the greater glacier had quite overridden the mouth of this valley on its northern side, while on the opposite side the striæ indicate that the tributary glacier filled Cwm Llydaw so high, that it overflowed its southern bank on Gallt-y-wenallt, where the ice rolled over the ridge south-easterly, and then curved round to the south, to swell the great glacier of Nant Gwynant. Whether under these circumstances, in the depths of Cwm-dyli

* See p. 74.

† *Teyrn*, a tyrant or supreme ruler. *Llyn Teyrn*, "King's Pool."

by the waterfall, an undercurrent of ice might have flowed easterly beneath the great mass that covered the mountain, I cannot determine; but it is needless to have recourse to it, since the striæ by the waterfall might subsequently have been produced by a diminished glacier, that in the latter days of the ice flowed through Cwm-dyli.

By the waterfall of Cwm-dyli there are symptoms of a small terminal moraine, and further up all through the valley, there are numerous moraine mounds, sometimes running up the valley in rude lines, some of the blocks on which are ten or twelve yards in diameter. Half a mile further, north-west of Llyn Teyrn, the rocks have been polished by ice, and the great bosses of greenstone, that rise in the midst of the valley like the hill behind the Grimsel Hotel, are nothing but huge *roches moutonnées*, dotted with felspathic blocks resting on their sides and summits. When largest, the glacier overflowed these (just as in old times the Aar glacier overflowed the hill behind the Hotel of the Grimsel), but as it declined, there are signs that seem to

indicate that it branched and wound between the islands of greenstone rock, and, decreasing still further, deposited its moraines in lines, where separate tongues of ice protruded from among them.

Approaching Llyn Llydaw, the full grandeur of this wonderful valley bursts on the beholder. A lake rather more than a mile in length and of a green colour*, like some of the lakes of Switzerland, obliquely crosses the valley. Around it rise the cliffs of Lliwedd, Cribgoch, and Pen Wyddfa, seamed with veins of white quartz that gleam like streaks of snow on the tall black rocks circling the vast amphitheatre, the scarred sides and ragged outlines of which, sharply defined against the sky, may well seem, till attempted, hopelessly inaccessible to the unpractised climber. In every season and phase of weather, there is a charm in this valley to the lover of the mountains. In quiet sunshine, when the rocks, and perhaps a lazy ferry-boat, are reflected in the still water; or while the wanderer scales the crags amid the

* About 1800 feet above the sea.

seething mists; or when the pitiless rain, or hail, or snow, comes driving down the valley; but best of all, in a threatening evening, when the gathered clouds, like the roof of a vast cavern, hang heavily from side to side on the edges of hills; and a streak of light caught from the setting sun, shows redly behind the dim peak of Snowdon, grimly reflected in the sombre waters of the lake.

The signs of a glacier are so evident in Cwm Llydaw that it is needless to describe all the details. At the outflow of the lake there are moraine-like mounds, formed of earthy matter, stones, and angular and subangular blocks, which even now partly dam up the lake, and when I first knew it, raised it to a still higher level, ere the channel of the brook was sacrilegiously deepened to lower the water, for the sake of saving a few pounds in the construction of an ugly causeway. Close to the outflow, the once beautiful little islets of rock, feathered with heath and grasses, are now united to the mainland, and a broad ugly black rim round the lake, marks alike the extent of the drainage, and the barbarism of the perpe-

trators of this unhappy outrage on the most beautiful scene in North Wales.

Between the upper part of Cwm-dyli and the north end of Llyn Llydaw, above the brook, there are magnificent *roches moutonnées*, once overflowed by the glacier; their sides and summits, from 200 to 300 feet above the lake, being still strewn with moraine débris and numerous *blocs perchés*. On the little peninsula below, the striæ running east-north-east show the direction of the flow of the glacier, which, unchecked by the hill beyond, passed right over the rocky barrier. From signs higher up the hill, I believe that at one period the ice must have been here at least 500 feet thick, and I incline to think that it was much thicker. On the opposite side of the lake, the moraine heaps, of large blocks, clay, and angular stones sometimes scratched, are remarkably apparent; and in the great recess below the cliffs of Lliwedd, the rocks are wonderfully rounded, and dotted with moraine matter and scattered blocks, at least 500 feet above the level of the lake. In the curve of that recess there are striations somewhat converging towards the

Roches Moutonnées, Blocs Perchés, and Moraine-Mound by Llyn Llydaw.

bottom, in the manner that might be expected to be produced by ice pressing both down the greater slope, and outwards towards the mouth of the valley; and well up, on the broken spur of rock that runs from Lliwedd towards the efflux of the lake, the striæ turn suddenly round more easterly, where once the ice flowed high across the ridge and escaped down Cwm-dyli into Nant Gwynant.

Beyond Llyn Llydaw, a white torrent leaps down the rocks that lead to Glaslyn, which lies about 2000 feet above the sea, in a semicircle of cliffs, close below the peak of Snowdon. This lake, if report speaks truly, it was actually intended entirely to drain, in search of some possible copper lodes, by an adit driven upwards from the broken ground above Llyn Llydaw! All round the lake the felspathic porphyries and consolidated ash-beds are *moutonnées;* and, even when most weathered, enough of these forms remain to attest their glacial origin. They are unusually striking on both sides of the stream, especially on the south, and on them scattered blocks stand perched in many precarious places. Striæ on the ice-

worn surfaces are also plentiful all round the lake. They run more or less easterly, in the direction that it is easy to see must have been given them by the gathered ice of this elevated recess seeking an outlet; and on the higher banks north, south, and west of the lake, they often slightly converge towards the bottom, in the manner we might expect from ice pressing down the banks, and at the same time outwards towards Llyn Llydaw.

Beyond Glaslyn, ascending the ridge by a zig-zag path that joins the Llanberis route to the top of Snowdon, or climbing the hills on the south side of the lake, it is easy to descend into the upper part of Cwm-y-Llan, a winding valley that leads to Nant Gwynant between Llyn Gwynant and Llyn-y-Ddinas.* Beddgelert may then be reached by a walk of less than four miles along the turnpike road.

Immediately below the peak of Snowdon in the bottom of Cwm-y-Llan, a moraine mound about half a mile in length runs nearly north

* *Ddinas*, a fortification or citadel. "Fortification Lake."

and south, formed perhaps in the latter days of the snow and ice that slipped from the high cliffs of Bwlch-y-maen* and Pen Wyddfa, or possibly from the broader opposite slopes between Bwlch-y-saethau† and Lliwedd. It consists of the usual heterogeneous assemblage of angular blocks, stones, and clay, derived from the hills above. These materials running in a somewhat waving curve, form a series of united mounds, which in general character are undistinguishable from many a Swiss moraine. Some of the fragments are scratched. Standing on the summit of the moraine, or seen from below, it forms a striking object, especially taken in connection with the ice-worn surfaces of rock on the sides of the hills. On these the striæ run more or less southerly, slightly converging towards the bottom of the valley. Farther down on both sides the glaciated aspect of the hill sides is still more imposing, especially on the slopes below Yr Aran‡, where the ice-worn surfaces contrast almost as

* *Maen*, stone. "Gap of the Stone."

† *Saethau*, arrows.

‡ The Peaked Mountain.

strongly with the craggy upper part of the ridge, as the *roches moutonnées* above the glaciers of the Aar do with the sharp serrations that form the crests of the mountains. In both cases the same tale is told, of a time when glaciers filled the valleys almost to the brim, and the upper edges of the mountains rising above the ice were scarred by rending frosts.

In the angular recess below the peak of Yr Aran, some of the striæ run north 25° east, and were formed at a period when the ice pressed directly down towards the bottom of the valley. At other places further down they strike east and east-south-east with the trend of the valley, then south-east in the narrow gorge by the mine, where—as with the Aar glacier below the Grimsel*—the pressure of the ice, forcing its way through the strait, ground the surfaces of rock so strongly, that to this day it seems as if the glacier had but lately disappeared. Below the gorge the striæ bend to the south, where the ice-flow curved round to join the great glacier, formed by the snow drainage of the

* P. 18.

valley of Llyn Llydaw and the mountains above Pen-y-gwryd, which, passing right down to Beddgelert and Pont Aberglaslyn*, formed the south-westerly striations that here and there mark the harder unweathered rocks of Nant Gwynant. No definite moraines occur in Cwm-y-Llan, besides that at the top of the valley; but débris and scattered blocks are numerous, and one of unusual size has been left by the retreating ice just above the gorge.

Such is a brief account of some of the most striking glacial phenomena round Snowdon. The mountain formed the centre of six glaciers that flowed from the direction of the peak down the valleys of Cwm Brwynog, Cwm-y-clogwyn, Cwm-y-Llan, Llyn Llydaw and Cwm-dyli, Cwm-glas, and Cwm-glas-bach. Two of these, from Cwm-dyli and Cwm-y-Llan, flowed into the larger glacier-valley of Nant Gwynant, two passed out to the west, and the glaciers of Cwm-

* Near Pont Aberglaslyn Buckland observed the striation of the rock, on the west side of the gorge. A framed inscription records it, in his own writing, in the hall of the Goat Hotel, Beddgelert.

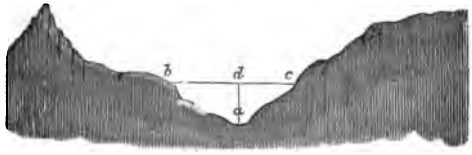
glas-bach and Cwm-glas contributed to swell the mass of the great glacier that descended the Pass of Llanberis. After a time spent in exploring these recesses, the mind readily embraces the whole subject, and a short walk from Llanberis on the heights of Snowdon, along the ridges from Llechog to Crib-y-ddysgyl and Blaen-y-maen*, enables the glacialist mentally to restore the whole series of glaciers that radiated from the central peak.

The fact that the valleys of North Wales were once traversed by vanished glaciers implies that the ice must have passed through several phases.

Before the Newer Pliocene period, and after the greater contours of the country were much as they are now, there were, probably, for a time no glaciers here. After this they began, attained a maximum size, dwindled, and disappeared. Reflecting on these things, it became an object with me, in the year 1854, to endeavour to ascertain what might have been the greatest

* Front of the Stone.

thickness of the ice in the Pass of Llanberis. For this purpose I made a series of observations with the sympiesometer, to determine the height above the bottom of the valley of the highest striations that run south-east and north-west, or in the direction of the flow of the glacier. The method was simple: first, by mapping the striæ I rendered myself familiar with the glacial phenomena of the valley. I then selected ten or twelve favourable points, and at each made first an observation with the instrument in the bottom of the valley, and then ascending the hills on both sides at right angles to it, I determined the height above the bottom at which striations were found running *along* the hills in the direction of the general fall of the Pass; thus:



PASS OF LLANBERIS.

a, the bottom of the Pass; *b*, *c*, the highest points at which striæ were observed running north-west along the sides of the valley; *a*, *d*, the thickness of the ice.

If, as I believe, the striations at *b c*, were made by a glacier that flowed down the Pass, then the line *a d*, represents approximately the thickness of the ice at one period of its history; and unless by long-continued erosion of its rocky floor, the glacier deepened the valley, the average thickness of the ice was from 1100 to 1300 feet. But the surface of the ice at *b c*, was higher than the present watershed of Gorphwysfa at the upper end of the Pass, and to produce a glacier-stream flowing down the valley and filling it to heights so great *half way down the Pass*, at the present watershed there must have been a mass of accumulated ice, not less than about 500 feet thick. That glaciers must deepen their valleys is self-evident, and therefore the above estimate cannot be strictly correct. But it is nevertheless of sufficient value to warrant the conclusion, that when the Welsh glaciers attained their largest size, the ice in the Pass was of very great thickness; and — considering the shape of the ground and the ice marks,—of a length so great, that it flowed well down across the lower hills that skirt Llyn

Padarn, in the manner shown by the striæ above that lake on the map.

It would be easy to give descriptions of other old glacier valleys in many respects as remarkable as those of Snowdon, more especially of Cwm-du beneath Mynydd-mawr, about a mile west of Llyn Cwellyn; of part of the country between the river Conwy, Afon Llugwy*, and Nant Francon; of the valleys leading up from Traeth Mawr † towards Cynicht ‡ and Moelwyn §; and of Cwm Orthin, near Ffestiniog, which I recommend all walking tourists to visit, and to look out for a series of magnificent *roches moutonnées*, and *blocs perchés* below the mouth of the lake, which are best seen looking down

* *Afon* means "a river," and *Llugwy* "the outbreak of the water." The word is very applicable when taken in connection with the source of the river; *Ffynnon Llugwy*, the "spring" or "source of the Llugwy." The moraine mounds that dam the lake have been cut through by the river in a manner suggestive of the bursting of a dam, though in reality it was probably only deepened gradually by the natural outflow of the water. See pp. 102, 103.

† Big Sands.

‡ *Cynicht* means a "basis" or "foundation;" but why the word is applied to this hill I do not know.

§ *Moel* is always applied to a round-topped hill. *Moelwyn*, "White Round Hill," or "White Hill."

the valley. But I refrain from such descriptions, and shall content myself with a brief account of Nant Francon * and some of its tributary valleys, which show, in a striking manner, all the familiar signs of glaciers.

Between Bangor and Bethesda (of late sometimes called Glan Ogwen), the lower ground is more or less covered by Drift, through which here and there bosses of glaciated rock protrude; as, for instance, on the eastern flank of Moel-y-ci †, near Pont-y-coetmor ‡, and in the neighbourhood of Bethesda.

South of the Penrhyn slate-quarries the valley narrows as we enter the Pass of Nant Francon, and the mountains rise grandly on either side; on the left in a long steep-sided hill, while on the right the ridge is bold, irregular, peaked, and penetrated by tributary valleys. In the bottom, between Ogwen Bank and the falls of

* *Francon*, or *Ffrancon*, is believed to be a corruption of *Avancon*, beavers—"Beavers' Valley." The river, often sluggish, winding through the alluvial flat, is just the sort of water to have been inhabited by beavers.

† *Ci*, a dog. "Dog's Hill."

‡ *Coetmor*, probably a corruption of *Coed Mawr*. *Pont-y-Coed Mawr*, Bigwood Bridge.

Llyn Ogwen *, the river wanders through marshes and flat meadows, which I often incline to think may at one time have been dammed up on the north, to form a lake, at a spot not far above the slate-quarries, where the Cambrian and Lingula grits, striking across the valley, have been ground by the old glacier of Nant Francon into *roches moutonnées*, as perfect as any in Wales. These are easily accessible on the left bank of the river, where I shall therefore describe them.

From Ogwen Bank to the ground opposite Tyn-y-maes †, for a distance of a mile, all the low ground by the river is occupied by smoothly glaciated undulating rocks, marked by numerous smaller mammillations, and dotted with erratic blocks, chiefly of felspathic porphyry. The larger curved surfaces are especially prominent, because of the hardness of the grits, which are here interstratified with softer slaty beds. The latter having been more

* *Ogof* means a cave. *Ogwen* probably means "White Cave;" but there are no caverns, either white or black, in the neighbourhood. It may probably be applied to the little gorge down which the white waterfall dashes.

† House in the field, or Field-house.

easily worn by the ice and reduced to a lower level, the grits stand out in relief*, and are strongly grooved, all the striæ running down the valley in a direction a little west of north. Any one who will take the trouble to ascend Cwm-ceunant† will also find striæ in the lower part of the valley‡, running in the same direction; and, what is more remarkable, on the ice-worn Cambrian grits that form the shoulder of Bronllwyd§, at a higher level than the Penrhyn‖ slate-quarries, well marked striæ follow the same course about 700 feet above the river, probably intimating that at a certain period the ice of the glacier was here at least of that height. This ridge is worth the ascent were it for nothing more than the view, from such a foreground, of the far mountain recesses that once formed the sources of the glacier. In the middle the sharp cone of Y Tryfan¶ rises like the fragment of a great

* This helps to throw light on the manner of formation of some of the rock basins that contain lakes. See pp. 104, 105.

† *Ceunant*, "Closed Valley."

‡ About half a mile W.S.W. of Pen-y-gareg.

§ *Bron*, a breast; *llwyd*, grey. "Grey-breast."

‖ A promontory.

¶ Three Peaks.

wall, seemingly inaccessible, although in reality it may be scaled without much difficulty among the shattered blocks of stone that lie in strange confusion on its steep western side. On the left of Nant Francon there rises the long ridge of Pen-yr-Oleu-wen*, gradually increasing in height, and ending in the broken cliffs of Craig-yr-hysfa†; and on the right are the recesses of Cwm Bochlwyd‡ and Cwm Idwal, the old parent-basins of the glacier, surrounded by the crags of the two Glyders, so steep that in places they are inaccessible.

In the bottom of Nant Francon above Pen-y-gareg, the signs of the glacier, from the nature of the rocks, become less striking. The slopes are, however, here and there sprinkled with travelled blocks, one of which, of large size, stands by the road at Pen-y-gareg itself. It is of felspathic porphyry, and was probably derived from the cliffs of Craig-yr-hysfa, or Cwm Idwal, from two to three miles off. Others lie on the very crest of the slaty ridge of Pen-yr-Oleu-wen, one

* Glow-worm Head, or Hill. † Hounding Crag.

‡ Pale or Grey Cheek. The name probably ought to be written *Bychlwyd*, a grey he-goat.

of which, about 2000 feet above the sea, is a block of felspathic porphyry nine yards in length, five high, and two in breadth. Its weight must be about 180 tons. Between Tai-newyddion* and Maes Caradoc†, by the road, the rocks are polished, and grooved; and opposite Ty-gwyn ‡ an excellent example of a *roche moutonnée* rises in the midst of the alluvial flat, presenting, as is frequent in such cases, its broken side down and its rounded side up the valley, in the direction whence the glacier flowed.

Between the Penrhyn slate-quarries and Capel Curig, fifteen tributary valleys branch from Nant Francon and the valley of Llyn Ogwen and Afon Llugwy. Eleven of these are on the west and south, and four on the east and north. The watershed in the Pass is at Wern-go-uchaf § near Llyn Ogwen, and it is easy to infer that west of this and Y Tryfan the high valleys of Cwm Bochlwyd and Llyn Idwal ‖ each contributed a great part of the ice that flowed down

* New Houses.
† Caradoc's Plain.
‡ White House.
§ Upper Blacksmith's Copse.
‖ Idwal, a man's name.

Nant Francon. Between Llyn Idwal and Bethesda, each of the six tributary valleys in some way or other tells that it was once the home of a glacier. At Llyn Cywion * in Cwm-goch, and in Cwm-bual † and Cwm-ceunant, there are scraps of moraines, and erratic blocks; or striated surfaces, on some of which, after removing the turf, I found that the ice-smoothed slate still retained a glassy polish, marked by scratches often as fine as if made with the point of a knife. Those in the upper part of the valleys always follow the general slope, but unfortunately when I examined North Wales, having other geological objects more especially in view, I became at length so familiar with striations, that I often neglected to record them, and I hesitate to draw them on the map, lest they should be out of place.

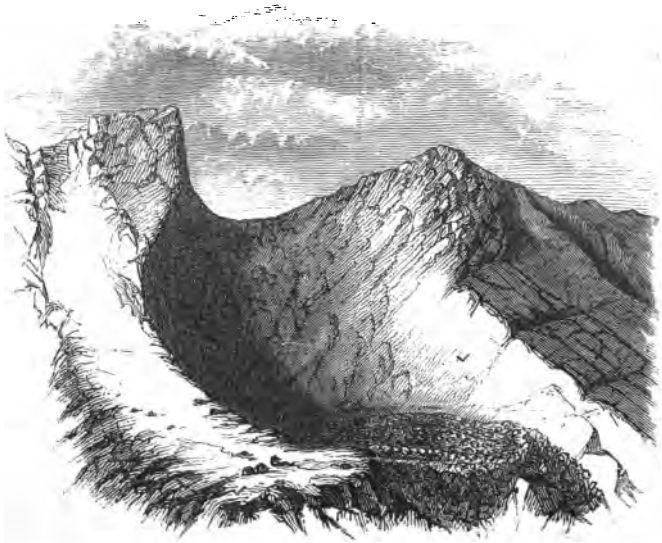
Taking Nant Francon in connection with its branching valleys, an attentive consideration of all the circumstances has led me to think that it was so far filled with ice, that the mouths of the minor valleys to a height of from 700 to

* Chicken's Pool. † Wild Bull, or Buffalo Valley.

1000 feet above the river, were overridden by the main stream of ice, which flowed across the lower ends of the spurs that branch from the crested ridge on the west. But, when by amelioration of climate the great glacier diminished, the lower spurs that bound the minor valleys stood out, partly denuded of ice, while the upland hollows still contained minor glaciers that left markings on the rocks more or less transverse to those that were formed when, from side to side, Nant Francon was almost full of ice. The same is the case with the existing glaciers of the Aar. (See p. 12.)

In none of the tributary valleys north of Llyn Idwal, are the signs of a small glacier so distinct as in Cwm-graianog *, which, on this account, is well worth a visit. From Bethesda it is easily reached from below, and from Llanberis the quickest route is up Cwm-dudodyn, and down what some would consider the perilous slope of Moel Perfedd, in a sort of *couloir* at the west end of the valley. The pedestrian then finds himself in a small

* Gravelly, or Stony Valley. See the description of the ground inside the moraine.



Cwm-graianog.

craggy valley over half a mile in length, looking across Nant Francon. On the east the felspathic porphyry of Moel Perfedd * rises in a rough peak, and on the west the great bare ripple-marked strata of the Lingula grits dip towards the hollow at an angle of 48° or 50°.

At the mouth of the valley above the steeper descent to Nant Francon, a small but beautifully symmetrical terminal moraine crosses the valley in a crescent-shaped curve, that once passed from 200 to 300 yards up the eastern side of the glacier. On this side, as might be expected, almost every stone of the moraine is a fragment of the felspathic rock of Moel Perfedd, having been shed from the edge of the glacier by a part of the ice that had that mountain as its source. Further west along the moraine, the material becomes mixed with fragments of grit and slaty sandstone; and by degrees, passing to the western side of the valley, the moraine matter consists entirely of pieces of the Lingula beds that form the crags of Carnedd-y-filiast †, on the right of the drawing. This will be appreciated by any

* *Perfedd*, the middle point.

† The Carn of the Greyhound-bitch.

one who has studied lithologically the sources of moraines, and the gradual mingling of material in the downward flow of some of the Alpine glaciers. In Cwm-graianog the whole is formed of large angular loose stones mixed with smaller débris, through which the drainage percolates. The largest of these lies on the top of the moraine, from 450 to 500 feet above Nant Francon. It was originally eleven yards long, nine broad, and about one and a half high, and when entire must have weighed nearly 300 tons; but it has been broken into four pieces by the frost. Two small lines of stones descend from the lower side of the moraine, looking as if they had been shed by ice from Cwm-graianog, even though where they lie below the great moraine, the rock still shows the north-westerly striæ formed probably at an earlier date by the great Nant Francon glacier. Inside the moraine, the bottom of the valley is covered with glacial rubbish and heaps of loose blocks, underneath which, in places, the water is heard flowing with a tinkling sound. Doubtless much of the finer débris has been carried away by the water, and the mounds may be partly the

result of the falling in of some of the material.

The valley of Llyn Idwal has long been classic ground to geologists, having been the first case in which a special glacier valley in Wales was described in detail.* Its features are simple. The rocks here consist of interbedded masses of grit and felspathic porphyry, lying in a synclinal curve, and forming on either side the tall cliffs of Y Garn and Y Glyder-fawr. The black wall of Twll-du†, famous for its ferns and saxifrages (the relics of an Alpine flora), closes the valley on the south-west, above which, by Llyn-y-cwn ‡, there is an upland valley, covered with angular drift, leading to the Pass of Llanberis. Below Twll-du, in the bottom, lie the sombre waters of Llyn Idwal, the depth of which I do not know, but which are partly dammed up by a terminal moraine, lowest in the middle, the greater amount of débris having,—as is usual with short glaciers—been brought down at the sides of the ice, where, under the circumstances, the sub-

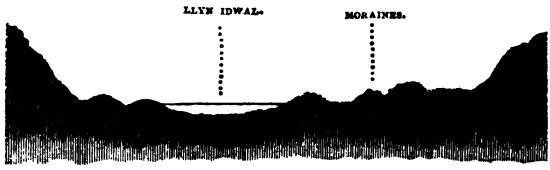
* Darwin, Phil. Mag. Ser. iii. vol. xxi.
† The Black Hole. ‡ The Hounds' Lake.

sequent removal of moraine matter was also less. The water is also, I incline to think, partly retained because it lies in a rock-basin, ground out by the old glacier. Below the moraine, all the way down to the Ogwen, the rocks are strikingly *moutonnées*, and where undecayed they are covered with striæ, which gradually curve round to take the direction of the main valley. Between Llyn Idwal and Cwm Cywion, on the top of the dividing ridge, high above the north-western angle of the lake, I found grooves running right across the watershed in the direction of Nant Francon; as if Cwm Idwal, before the glacier dwindled to form the still-existing moraines, had at one time been full of ice, at least to the height of these striations, thus overflowing the barrier that divides it from the west side of Nant Francon. If so, it may be that at this period, or when still larger, it abutted on the opposite mountain below Braich-du*, thus producing the remarkable smoothing of the rocks far up the cliff, and striating them transversely to the slope of

* The Black Arm.

the hill, in the direction in which the ice under the circumstances escaped down the valley.

As the glacier decreased in size it deposited the moraines that now skirt Llyn Idwal, its progressive decrease being marked on the western



SECTION ACROSS THE MORAINES OF LLYN IDWAL.

side of the lake by four moraines arranged in long symmetrical mounds one within another. There is also some appearance of an inner terminal moraine towards the southern end of the lake, where it narrows; and on the east there are patches of moraine matter, and ice-smoothed bosses of rock rising through the soil.

Descending to the outlet of Llyn Ogwen, very perfect *roches moutonnées* mammillate

the hill side and lie in the bottom, covered with straight grooves, running in the direction of the valley. Similar signs mark the lower part of the mountain on the angle of Craig-yr-hysfa, and ice-smoothed rocks, perfect or decaying, rise so high up the mountain towards Braich-du, that, to appreciate them, it is necessary to scramble along and up and down the face of the mountain almost from bottom to top. Some of these were probably made by grating icebergs during the partial submergence of the country.*

Above Llyn Ogwen, in Cwm Bochlwyd, there are again ample proofs of glacier action. A little lake lies in the hollow of this, one of the wildest valleys in North Wales, apparently slightly dammed up by moraine matter; and just beyond the upper end of the lake, there is an immense moraine heap, running nearly across the valley, and formed of angular blocks of stone, some of them from six to ten yards in length. Occasionally, these are marked by straight striæ, which do not cross each other;

* See p. 92.

showing that these blocks once formed part of the sides of the glacier, and that when it diminished, some of them, rent by the weather, fell on the ice, and were floated down to swell the mass of this moraine. Frequent *blocs perchés* here, as at Llyn Idwal, dot the *roches moutonnées*, and it is important to note that above Llyn Bochlwyd, striations run south-easterly right up to the summit of the steep and shattered ridge that unites Y Glyder-fach to Y Tryfan; so that here, on the old snowshed, it would appear that the ice pressed downwards in opposite directions into Cwm Bochlwyd and Cwm Tryfan, and afterwards curving round, helped to form the glaciers that flowed northerly through both valleys on opposite sides of the sharp peak of Y Tryfan. In this, on a small scale, it resembled some Alpine Passes, where, standing on the apex of a gently sloping snowshed, you look down upon opposite systems of drainage.

To avoid statements similar to those already made, it is now enough to say, that in the wild rarely visited mountain tract, that lies between Bangor, Capel Curig, and Conway,

there is not a mountain, valley, or lake, that to the instructed eye does not show either signs of the influence of glaciers, or, more strongly still, of the icy sea of the DRIFT; and I shall now turn to the consideration of the relations of the glaciers of North Wales to these remarkable marine deposits.

Every one who has given any attention to Tertiary geology is aware that a large portion of the low country of the north of Europe, from the Ural to the Atlantic, is more or less covered by what is technically termed DRIFT; that is to say, of loose superficial accumulations of sand, gravel, and clay, charged with rounded, subangular, and angular stones and boulders, many of which have travelled for hundreds of miles. Thus the great plains south of the Baltic are covered with fragments of granite and gneiss derived from the Scandinavian chain, an instance of which will occur to many, who remember opposite the Museum at Berlin the great vase or tazza of polished granite, made from a boulder found in the neighbourhood. The plains of Siberia are in

great part formed of so-called *diluvial deposits*, which, according to Chihacheff, penetrate the mouths of the valleys on the flanks of the Altai, and shows many analogies with the Drift, even though it is doubtfully said to contain no erratic boulders; and all the broad champaigns and table-lands of North America, from the St. Lawrence to the Ohio, are covered by gravel and clay, well sown with boulders, many of which have travelled hundreds of miles from the gneissic mountains north of the St. Lawrence. The east coast of England, from Yorkshire to Essex, is in like manner covered by Drift, partly of Scandinavian origin, and all the solid formations of the central plains, from Leicestershire to Worcestershire and the borders of North Wales, are more or less obscured by detritus well charged with boulders, many of which have been transported from Cumberland, and perhaps from Scotland, and Wales itself.

For long it was a favourite dogma that these heterogeneous mixtures of near- and far-transported material were scattered over the northern continents by great sea waves, which, rushing

from the north, strewed half a world with rubbish, and thus polished and striated the rocky surfaces over which the débris passed. But now that spasmodic geology is at a discount, more sober imaginations believe that the blocks of stone that strew our continents and islands were chiefly dropped where they lie, by the same agency—that of icebergs—that is now sowing the Western Atlantic with earth, and erratic boulders, derived from the mountains and coasts of Greenland, where glaciers descend to the sea. The question then naturally arises, What is the relation of the DRIFT to the glaciers that once existed in our own regions?

First it must be stated, that the occurrence of this Drift high on the mountains, introduces an element of great difficulty in accounting for some of the details of the glaciation of a country like North Wales; in so far that it is sometimes impossible to decide which of the striations were produced by glaciers, and which by icebergs*; for, when the land was deeply submerged, and the mountain tops formed

* See p. 88.

a group of islands, striations must have been formed by icebergs grating on the sides of the channels (now elevated valleys) through which they floated, and it is impossible always to separate these from striæ formed by glaciers of later date. It is probable, as I have elsewhere stated*, that an earlier and greater set of glaciers preceded the deposition of the Drift, but whether or not this was so, does not interfere with the fact, that after the re-elevation of the drift-covered country, the greater glaciers ploughed the drift out of some of the larger valleys, and during that process produced those striations that still seam their sides. An instance of the difficulty occurs in the main valleys between Llyn Ogwen and Capel Curig, and between Capel Curig and Pen-y-Gwryd. In the former case, the higher striations on the flanks of Carnedd Dafydd *may* have been produced by icebergs during the submersion of the country, and at a time when drift was deposited in the valley of the Llugwy, and probably also in Nant Francon. But at a later date, after re-elevation, this drift has been ploughed out of

* Geol. Journ. vol. vii. p. 371.

Nant Francon by a large glacier, while it still remains in the valley of the Llugwy. The slope of the country seems to have sent the moving ice that gathered in Cwm Idwal and Cwm Bochlwyd, all down Nant Francon, leaving, in the valley of the Llugwy above Llyn Ogwen, the Drift still lying intact on mammillated and grooved surfaces of rock.

The above remarks will prepare the uninitiated to appreciate the well-ascertained fact, that previous to the Tertiary glacial epoch, most of the grander contours of hill and valley were in Britain (and elsewhere in Europe and America) nearly the same as now. Much of the land was then slowly depressed beneath the sea. As it sank, its minor features were modified, for terraces were formed on old sea margins, and icebergs drifting from the north, and pack-ice on the shores, ground and grated along the coasts and sea bottoms, smoothing and striating the rocky surfaces over which they passed, and depositing, in the course of many ages, clay, gravel, and numerous boulders over wide areas that had once been land. The grooves and striations on the ice-smoothed rocks (except

where locally deflected) still bear witness to the general southward course of the ocean currents that bore the ice from its birthplace into milder climates.

All through Britain and Ireland this Drift rises well up on the flanks of the mountains; and in Caernarvonshire, and North Wales generally, the surface is, over large areas, more or less covered by true GLACIAL DRIFT, rising from underneath the sea to a height of about 2300 feet on some of the mountains. Near the shore, it has often been re-arranged and worn by the sea at a later period, while emerging, or during terrestrial oscillations of level, and it is in this upper division that most of those shells, &c. are found, which are usually considered characteristic of the Newer Pliocene deposits. But in the high grounds the Drift is generally in its native state, consisting of clay, angular stones, gravel, and boulders, sometimes, as in Cwm Llafar, on the west flank of Carnedd Llewelyn *, arranged in terraces marking pauses in the re-elevation of the country. Shells were found

* Near Glan Ogwen or Bethesda.

by Mr. Trimmer, on Moel Tryfan near Nant-y-llef, 1300 feet above the sea, in sand and gravel; and others were found by myself at about the same height, two miles west of the peak of Snowdon, on a sloping plain of drift charged with erratic blocks, one of which, of great size, is known as *Maen-bras*, or the large stone.

Much of this Drift, though rudely stratified, singularly resembles ordinary moraine matter in the appearance and quality of its mud, and the polish, approximate angularity, scratched surfaces, and sizes of its stones. From circumstances presently to be mentioned, it is to me certain, that at a time when North Wales was so far submerged that only the higher mountain tops rose as islands,—none of them more than about 2000 feet high — some of these even then gave birth to glaciers that descended into the sea, their ends breaking off in icebergs, which floated hither and thither, and melting, deposited their stony freights. The intensity of the cold may be inferred from this. The sea then flowed through some of the greater valleys between the Menai Straits and Cardigan Bay, across

Maen-bras, West of Snowdon.

the present watersheds of the Passes. The principal of these are the Vale of Conway, and its upper branches to Capel Curig, &c.; the Pass of Nant Francon, and its continuation between Llyn Gwynant and Capel Curig; the Pass of Llanberis (about 1000 feet high at the watershed), opening into Cwm Gwynant; and the Valley of Afon Gain, between Caernarvon and Beddgelert. The country was thus broken into a group of islands, each one of which in great part had its covering of snow and ice, permanent, till large cosmical changes produced a decided amelioration of climate.

It is, therefore, not improbable that before this change took place, in portions of these islands not possessed of the form requisite to originate massive glaciers, snow and glacier ice may nearly have covered their entire surfaces; for, unless the cold were sufficient to produce such a result, it is difficult to understand how on other parts of these small islands, good-sized glaciers, such as then certainly filled the valleys, could have been produced. But if this covering of snow and ice did exist, it is very intelligible how the Drift on the sides of

the mountains is not only generally composed of stones from the hills close above, but is also more or less moraine-like in its character. In fact it is not till we reach the low ground of Caernarvonshire, near the sea, and the plains of Anglesey, that far-travelled fragments from doubtful or unknown regions begin to occur in Drift deposits which are perfectly distinct from glacier moraines, although resting on ice-smoothed and striated surfaces, the directions of the striæ on which bear no relation to the glacier valleys of Caernarvonshire, but run transversely to them, and were, in my opinion, produced by icebergs floating mostly from N.N.E. Under any such circumstances, icebergs and coast-ice grating along the shores and sea bottoms, would in the course of time be sufficient not only to smooth and groove the rocks, but also to scratch blocks and stones that lay in the bottom of the sea or were imprisoned in the floating ice.

Between the valley of Llyn Cwellyn (Cwm Seiont *) and the lakes of Llanberis, there is a

* *Seiont* or Segontium.

wild and high moorland tract almost entirely covered by Drift, till we reach the solid rocks above Llyn Padarn. Just above either side of that lake, the hills are generally craggy, or else *moutonnées*, and clear of Drift; and beyond Clegyr towards Nant Francon, west of the mountains of Elidyr-fach and Bronllwyd, there is a corresponding broad moor formed by Drift of great thickness, which, from an average height of about 1100 to 1300 feet, stretches eastward into the valley of Marchlyn-mawr, where it attains an elevation of about 2000 feet. Standing on this moor, above the left bank of the Ogwen, the eye easily detects on the opposite slopes a corresponding accumulation, stretching smoothly up the country towards Aber, and bending on the east and south-east towards the valleys of Afon Berthan*, the Llafar, and Afon Gaseg†, streams that rise in the higher recesses of Carnedd Dafydd and Carnedd Llewelyn‡, on their seaward flanks. In the valleys through which these streams flow, the

* *Berthan*, a bush, "Bushy Brook."
† *Gaseg*, a mare.
‡ David's Carn and Llewelyn's Carn.

Drift attains an elevation of about 2300 feet, stretching into their wide recesses with a smooth outline, and I was informed * that part of these deposits contains shells at a height of about 1000 or 1200 feet.

Cwm-llafar † has an interesting history, and is worth a visit, being easily reached from Bethesda or Glan Ogwen. A vast semicircular hollow surrounded by the black crags (chiefly greenstone) of Carnedd Dafydd, Carnedd Llewelyn and Yr Elen ‡, forms the upper end of the valley. In its bottom, between the last-named peak and Mynydd-du §, the Drift, thickly charged with angular boulders, often of large size, forms a succession of terraces, the result of marine denudation during pauses in the re-elevation of the country after its submersion to a depth of more than 2000 feet. On the south-western side of the valley there is a long and comparatively narrow channel, through which the brook runs, *bare of Drift and boulders*, and having on the Mynydd-du side a

* By the late Mr. Joshua Trimmer.

† *Llafar*, a voice; alluding to the echoes of this semicircular hollow.

‡ *Elain*(?), a fawn.

§ The Black Mountain.

well-marked *roche moutonnée*, striated in the direction of the valley, thus marking the course of a narrow glacier about two miles in length, *that ploughed out a long narrow hollow in the Drift.* That this clearance was not effected by the existing little stream is evident; for it is utterly inadequate to remove the blocks that form the bulk of the terraced drift. The removal by running water of the lighter detritus mixed with these would, indeed, have *concentrated* the boulders on the surface of the straight alluvial hollow, in the manner they now are concentrated by river denudation on the banks of the far more powerful Gorfai, two miles S. and S.E. of Caernarvon.* As the Cwm-llafar glacier decreased in size, it deposited a minor terminal moraine where the brooks meet below Nant-bach and Nant-y-craig. Within this barrier a small lake seems to have been dammed up, till the brook at the outlet cut a channel to the bottom of the moraine, and the water of the lake was drained away.

* On a grander scale this concentration of boulders is well seen in places on the lower terraces of the rivers St. Lawrence and Ottawa.

The same ploughing out of the Drift by glaciers on a much larger scale is evident in the Passes of Nant Francon* and Llanberis. In the latter case this was effected as far as the lower end of Llyn Padarn, on either side of which, and of Llyn Peris, the glacier, having escaped from the narrow Pass, spread itself over the high grounds by the slate-quarries; and also flowing across the top of Clegyr, as shown by the striations marked on the map, it left the Drift untouched towards the Turbary plain that lies between Clegyr and Bethesda.

Before leaving the subject of the Welsh moraines and Drift, I must again call attention to the fact that many of the lakes are partially dammed up by moraines, and some of them apparently owe their existence to these mounds in a manner altogether peculiar.

The mouth of a valley is surrounded by a mound or series of united mounds curving outwards, formed of earth, angular, subangular, and sometimes smoothed and scratched stones,

* Long since noticed by Mr. Darwin.

so truly moraine-like in their arrangement, that their origin and the places whence they came are unmistakeable. A deep clear lake lies inside, and the drift of the glacial sea, full of boulders, slopes right up to the outside base of the moraine, with a long smooth outline, showing that the glacier descended to the sea level, and pushing for a certain distance out to sea, formed a marine terminal moraine, while ordinary drift detritus, partly scattered by floating ice, was accumulating beyond. In the meanwhile the space on and beyond the sea level occupied by the glacier was kept clear of débris; and when the land arose, and the ice disappeared by an amelioration of climate, the hollow within the terminal moraine became replenished with the water drainage of the surrounding hills, just as in earlier times it was filled with ice formed by a drainage of snow.

Such in Caernarvonshire are the lakes of Llyn Dulyn* and Mellynllyn†, about two miles N.E. of Carnedd Llewelyn; of Fynnon Llugwy, between Carnedd Llewelyn and the road from Llyn Ogwen to Capel Curig; of Cwm Elen, and

* *Dulyn*, Black Pool. † Yellow Pool or Lake.

of Marchlyn-mawr* and Marchlyn-bach†, in the high recess between Elidyr-fawr and Moel Perfedd, near the path from Llanberis to Nant Francon. Judging by the present average elevation of some of these lakes, when the moraines that confined them were formed, the highest parts of the mountains of Caernarvonshire could not have been more than from 1400 to 2000 feet above the sea.

In those cases where ordinary terrestrial moraines form the confining barriers of mountain lakes and tarns, it is, as already stated, not to be supposed that the depths of these moraines is always equal to the profoundest depth of the lakes. The contrary, I venture to say, is often the case, although I had no opportunity of sounding Llyn Llydaw, Llyn Idwal, and several other deep lakes, where I believe this will be found to be true. I have already said, that it seems to me probable that such rock basins were ground out by heavy loads of ice, which in their onward progress scooped deep hollows in parts of their channels; and this might easily be the case, when this grinding

* Big Horse Pool. † Little Horse Pool.

action lasted after a glacier had retired above the position of the present lake barrier, so that the waste of the rocky floor being long continued, by degrees the glacier wore out a depression deeper and deeper, till on its final retirement the space once occupied by ice, became filled with the water drainage of the valley. As in Wales, so also I believe that this was probably the case in the valley of the Aar, above the Kirchet. It also seems probable that the same process helped to form the hollow of the Märjelen-see, on the east side of the low ridge covered by ice that separates that valley from the deeper hollow through which the Aletsch glacier descends.

This most interesting lake is bounded on the west by a protruding portion of the Great Glacier of Aletsch, ending in a cliff of ice, from which fleets of small icebergs frequently break. In older times a branch from the main glacier filled the space now occupied by the lake, and passing further east united the glaciers of Aletsch and Viesch. But a change of climate lessened the size of the Alpine glaciers, the uniting stream of ice gradually melted, it

tween the Märjelen-see and the ridge beyond the Bettenhorn, and I was surprised to find that a large part of the ice-cliff I had walked along had broken away, and was floating about the lake in a prodigious number of white icebergs, some of them bearing stones and boulders, like the bergs in a little fiord of an Arctic Ocean. As they melt these bergs discharge their occasional freights over the bottom of the lake. The day after, while enjoying the scene, one of them, becoming topheavy from the more rapid melting of the ice below the water, rolled completely over with a great roaring noise of displaced waters pouring down its sides, calling to mind the descriptions by Arctic voyagers of the turmoil caused by the occasional complete reversal of the great icebergs of the Atlantic that have travelled from the coasts of Greenland.

In still weather many boulders may be seen scattered over the bottom of the Lakes of Llanberis; and since visiting the Aletsch glacier I have often thought, that an episode, in the glacial history of the Pass may have been that these blocks of stone were scattered by icebergs.

An Episode in the History of the Pass of Llanberis.

broken from a glacier that descended into the lake, like the cliff of ice that now overlooks the Märjelen-see.

The erosion of such hollows by ice also seems strictly analogous to that which scooped out the more perfect rock-basins, not only of lakes and pools in ordinary glacier-valleys (such as those of Cwm-glas on Snowdon, and of Llyn Cywion above Nant Francon), but also of those that lie on high passes and watersheds, like the Todten-see, between the Grimsel and the Valley of the Rhone; or again, on high surfaces, like the tarns on some of the rough table-lands between Ffestiniog, Nant Gwynant, and the river Conwy; or, on the once mammillated but now half-weatherworn surfaces of gneiss, where a network of pools, tarns, and lakes by the score, may be seen from the sharp peak of Suilven, in Sutherland, the basins of many of which were seemingly scooped out, when, like the north of Greenland, the land, all save the roughest crags, was covered by a vast sheet of thick ice that descended below the present level of the sea. The producing cause of these peculiar hollows that I have seen in

Wales and Switzerland, was, I believe, an immense weight of superincumbent ice pressing and grinding *downwards and outwards*, over high, flat, and sometimes broad watersheds and table-lands, during that period of intensest cold that produced the glaciers of Wales, and the great original extension of the glaciers of Switzerland.

The gradual destruction of ice-worn surfaces is also a point of considerable interest, for, though these signs endure for many ages, still, in a geological sense, they are hastening to decay. When the turf and glacier débris is removed, though the underlying surfaces of cleaved slate often retain a perfect ice-polish, yet, after long exposure, the smoothness and finer markings disappear; and though the general rounded form remains, the surface becomes roughened, and the highly-inclined cleavage planes present on their edges a slightly serrated aspect. The deeper flutings, however, often last for a long time; but even these at length vanish, though it is not until long after this has been effected that the general rounded

form of the *roches moutonnées* is entirely obliterated.

Phenomena of the same general nature are observable in the igneous and other uncleaved rocks over which a glacier has passed. The original polished surface, on exposure, becomes roughened by atmospheric disintegration; but the general form long remains to attest its glacial origin, and in no case is there any danger of the experienced eye confounding this with those forms in gneiss produced by spherical decomposition, about which so much has been written. Finally, in the long lapse of time, air, water, and repeated frosts do their work, the rock splits at its joints, crumbles, masses fall off, and by degrees it assumes an irregular and craggy outline, altogether distinct from the glaciated surface produced by the long-continued passage of ice; and thus it happens that on the very summit of some tower-like crag, the sides of which have been rent by the frosts of untold winters, the student of glacial phenomena sometimes finds yet intact the writing of the glacier; while below on its sides all trace of the ice-flood has long since disappeared. These things may

seem almost incredible to those who are unaccustomed to read the records of many terrestrial revolutions in the rocks; but, nevertheless, of these extinct glaciers it is true, that just as a skilful antiquary, from the wreck of some castle or abbey of the Middle Ages, can in his mind's eye conjure up the semblance of what it was when entire, so the geologist, from the signs before him, can truthfully restore whole systems of glaciers that once filled the valleys of North Wales.*

But these things being true, what relation in Time is there between the old glaciers of Switzerland and those of Wales? The elements from which to attempt a solution of this question are few. First, it may be said that the signs of glaciation in the former extension of still existing Swiss glaciers, are not only identical in all respects with those of the extinct glaciers of Wales, but also that in many an Alpine valley all the ice-marks remain, even

* And in like manner of the Highlands of Scotland, and of Ireland, and the mountains of the Vosges. See Hogard and Dolfuss-Ausset. "Coup d'Œil sur le Terrain erratique des Vosges, 1848."

when no diminished glacier still holds its place amid its uppermost recesses. These in all respects may be compared to the ancient glaciers of the neighbouring Jura, the Vosges, or of Wales. Again, when we consider that the great old glaciers of the Oberland apparently opened out on the broad drift-covered territory that extends northward to the Jura, there is another point of resemblance. So similar in general structure and in all its adjuncts is this Drift with that of the north of Europe, that I see no reason whatever to doubt their identity. To add weight to this opinion, I may quote the high authority of Mr. Smith of Jordan Hill, who has long made a special study of the Drift and is convinced of their identity. Further, it is well known that in the more superficial deposits associated with these, the bones of the great hairy elephant (E. primigenius), and other mammalia remains, occur by the Lake of Geneva, near Zurich, and in other places. Besides these circumstances, though no one that I know of has yet proved the ploughing of drift out of the mouths of Swiss valleys by the older and larger glaciers, yet in every other respect the

conditions are so identical, that I am prepared to expect that this also will be proved; and I cannot resist the conclusion that, when glaciers filled the valleys of Wales it was at that very time (the Newer Pliocene epoch) that the glaciers of Switzerland attained their great original extension.

Further, in spite of the modern fact that far south of the equator the cold is greater than in equivalent northern latitudes, it is difficult not to speculate on the probable existence of a climate colder for nearly the whole world, during what is often called the glacial period; a period when the Alps, and all Scandinavia, were full of great rivers of ice descending to the sea; when the White Mountains of North America also had their glaciers*, and when the great glaciers of the Himalaya, as described by Dr. Joseph Hooker, descended 5000 feet below their present levels, the older moraines being in one instance only 9000 feet above the sea, whereas the present end of the glacier lies at a height of 14,000 feet.

* So I was informed in 1857, in conversation with Agassiz.

Another point often occurs to my mind,—what relation have these extinct glaciers to the human period? This is a subject on which we still are in the dark, but considering that in Newer Pliocene bone-caves flint knives have been found,—there is reason to believe coeval with elephants, rhinoceroses, and other Mammalia partly extinct;—and that in France, at Abbeville and Amiens, well formed flint hatchets of an old type occur in fresh-water and marine strata of so-called *Upper Tertiary* date; that two human skeletons (one with a skull of strange and antique type) were discovered near Maestricht under ten feet of Loess *; and also, that a human skull was dug out of the so-called Pliocene volcanic tuffas of

* This formation belongs to the same general period with the Drift, but is perhaps a little younger. I have seen the skull in the possession of Professor Schaffhausen of Bonn, who states that the discoverer affirms that the Loess was quite undisturbed previous to the finding of the skeletons, and he sees no reason to doubt the statement. Professor Schaffhausen also possesses the cast of a skull of similar form found in a limestone cave in the Neanderthal near Hochdal, between Düsseldorf and Elberfeld. It occurred in the manner usual in bone caves, but no other bones were found along with it.

Auvergne under circumstances at the least suspicious, it is possible, and perhaps even probable, that, long after the Drift was raised above the sea, the eyes of men may have looked upon the glaciers of Wales, when, in their latter days, the ice had shrunk far up into the highest recesses of the mountains.

THE END.

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Maps.

1. The Mont Blanc Range
2. The Mountains and Glaciers of Bagnes
3. The Glacier of Zinal, and the adjoining Mountains
4. The Range of Monte Rosa
5. The Saas Grat and the Fletsch-horn
6. The Glaciers of the Oberland
7. The Bernese Alps from the Oldenhorn to the Wildstrubel
8. The Alps of Glarus and part of the neighbouring Cantons
9. Map illustrative of the Ancient Glaciers of Part of Caernarvonshire

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